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PEANUTS AND GEORGIA

Three years ago, Joseph B. Hosmer concluded his Georgia Tech Engineering Experiment Station Special Report on *The Need for More Peanut Processing Plants in Georgia* with four recommendations: (1) agricultural, processing, and marketing problems must be subject to exhaustive research, (2) farm management must act on research results which increase per-acre yield and reduce growing cost, (3) processors must utilize sound engineering management and council in plant operations, and (4) national markets should be promoted both for peanut products as a class and for individual brands.

Even three years ago it was evident that peanut growers and marketers would have to exert extraordinary efforts to maintain the high-level balance of production and sales which was gained during the war. That overproduction would prove a serious problem was only too evident. That it is now such a problem can be judged by last year's Department of Agriculture decree which reduced acreage sown to peanuts by an average of 22 per cent, and by the much-bemoaned further cut of 20 per cent for 1950 from the planting permitted last year. In 1949, despite the acreage cut, Commodity Credit Corporation purchases of surplus peanuts exceeded 250,000,000 pounds.

For the Georgia-Florida-Alabama area, which produces more than half of the nation's peanuts, reduction in planting is attended by unemployment, loss in revenue, and consequent loss in buying power. There is thus no question that attention—immediate attention—must be given to creating new markets for peanuts and to increasing the demand for present products. More plants are needed to produce peanut butter, peanut spreads, peanut cooking

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President Truman, in his recent message to Congress, foresees the day when the average wage will be $12,000 per year. Such a figure is not impossible of accomplishment; the question is, will this wage, if and when reached, buy more in real goods than present salaries? If it is attained simply by an inflationary spiral of wage and price increases, the victory would be hollow indeed.

How, then, can a real triumph be achieved? Science and technology provide the key to the answer—research; research on better methods of producing goods at lower prices; research on development of new and less expensive products; research in the fields of management and marketing; in short, research into every phase of modern industry which will lead to more goods and services at lower unit costs. In such efforts, technological institutions such as Georgia Tech have a definite role to play.

BLAKE R. VAN LEER

President, Georgia Institute of Technology

WATER AND SUPERSONIC AERODYNAMICS

By H. W. S. LA VIER*

Recent research activities here have indicated the possibility that water will be an important medium in the study of the aerodynamics of high-subsonic and supersonic flow. Aeronautics School researchers have applied the familiar "hydraulic analog" in conjunction with a 20 ft. x 4 ft. shallow water channel in a search for a convenient and inexpensive tool for use in supersonic aerodynamic research. Excellent agreement has been obtained between water channel and wind tunnel test results in connection with profiles that have been previously tested in the wind tunnel. Preliminary tests, however, have indicated the necessity for thorough development of the experimental techniques involving proper placement of the recording cameras, measurement of the meniscus and application of a suitable correction for it, and accurate measurement of the local water depths. The two-dimensional nature of water channel test results has so far proved to be its most serious limitation.

It has been known for some time that an analogy exists between water flow with a free surface and two-dimensional flow of a compressible gas. Riabouchinsky[1] first presented the mathematical basis for the hydraulic analogy and applied it to the flow in a laval nozzle. Binnie and Hooker[2] further investigated the application of the hydraulic analogy by obtaining surveys along the center of a channel with a constriction. This work was rewarded by their obtaining an entirely satisfactory agreement between the compressible gas flow theory and the analogous hydraulic results. Ernst Preiswerk,[3] at the suggestion of J. Ackeret, conclusively proved that an analogous relation existed between water flow with free surface and the methods of gas dynamics.

In 1940, the National Advisory Committee for Aeronautics constructed a water channel for use in the investigation of the applicability of the hydraulic analogy to flow through nozzles and about circular cylinders at subsonic velocities. These studies were extended into the supercritical velocity range.[4] Satisfactory agreement was found between the water flow and air flow about similar bodies, although it was concluded from this work that obtainment of accurate, quantitative results would require additional investigations, both theoretical and experimental.

In the postwar period, North American Aviation Incorporated recognized the possibility of extending experimental compressibility research by use of the hydraulic analogy. In 1946, they constructed a shallow water channel through which test models were drawn, the water flow about them being recorded by cameras and other means. These studies convinced North American experimenters that, with accurate equipment, quantitative as well as qualitative results could be expected from water channel experiments.[5]

The close coincidence of the speed of sound and the wave propagation velocity for a compressible gas has resulted in scientific interest in the much-publicized "speed of sound," or sonic velocity. The appearance of surface waves on the shallow water and the flow conditions at sonic velocity have been found to be quite similar. Particularly, the "hydraulic analog" is comparable to the flow of a compressible gas having a gas constant $\Upsilon = 2.0$ (where Υ is the ratio of the specific heat of a gas at constant pressure to the specific head at constant volume). Such a gas is closely comparable to air, which has an approximate gas constant of $\Upsilon = 1.4$.

The analogy between the flow of water with a free surface and the flow of a compressible gas may be obtained by setting up the energy equations for the two flows. For water, the energy equation yields

$$V^2 = 2g\,(d_0 - d), \text{ and}$$

$$V_{max} = 2gd_0,$$

where: V = velocity of flow,

g = acceleration due to gravity,

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TABLE I

Analogous Relations Between Gas and Water Flow

Two-Dimensional Compressible Gas Flow ($\Upsilon = 2$)	Incompressible Liquid Flow (Water)
Temperature ratio, T/T_0	Water depth ratio, d/d_0
Density ratio, p/p_0	Water depth ratio, d/d_0
Pressure ratio, P/P_0	Square of water depth ratio, $(d/d_0)^2$
Velocity of sound, $a = \sqrt{\frac{P\Upsilon}{p}}$	Wave propagation velocity, $a = \sqrt{gd}$
Mach number, $M = \frac{V}{a}$	Mach number, $M = \frac{V}{\sqrt{gd}}$
Shock wave	Hydraulic jump

d = local water depth at any point in the flow field, and

d_0 = stagnation or undisturbed water depth in the field.

For the gas flow, the energy equation yields

$$V^2 = 2gC_p \ (T_0 - T), \text{ and}$$

$$V_{max} = \sqrt{2gC_p T_0},$$

where the terms V and g have the same definition as for the water flow but

C_p = specific heat at constant pressure,

T = absolute temperature of the gas at any point in the field, and

T_0 = undisturbed or stagnation absolute temperature of the gas in the field.

By equating the ratios of V/V_{max} for both the water and gas, it follows that

$$\frac{d_0 - d}{d_0} = \frac{T_0 - T}{T_0}, \text{ or } \frac{d}{d_0} = \frac{T}{T_0}.$$

This demonstrates that the ratio of water depth corresponds to the ratio of gas temperatures. Since it is known that for adiabatic gas flow the relation

$$\frac{p}{p_0} = \left(\frac{T}{T_0}\right)^{\frac{1}{\Upsilon - 1}},$$

therefore, for the gas where $\Upsilon = 2.0$, the above relation becomes

$$\frac{p}{p_0} = \frac{T}{T_0}.$$

Finally, it is plain that the hydraulic analogy is based upon the following relations:

$$\frac{p}{p_0} = \frac{T}{T_0} = \frac{d}{d_0}.$$

These analogous relations are summarized in Table I.

Two types of water channels may be used for experimental application of the hydraulic analog. Prieswerk and the National Advisory Committee for Aeronautics used a channel which permitted a steady flow of fluid past a fixed model. This type of channel enables the experimenter easily and quite accurately to measure the local depth of fluid about the model profile and at any point in the test field. Conversely, North American Aviation chose to draw the model through the shallow water. In this type of

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PARTICLE SURFACE AREA STUDIES AT GEORGIA TECH

By CLYDE ORR, JR.*

In the May, 1949, issue of THE RESEARCH ENGINEER, a description was made of "Fine Particles Research at Georgia Tech." The following article is the first of an intermittent series which will describe such research in more detail.

In recent years, increased use of powdered materials in the manufacture of many commercial items has caused industry to become acutely aware of the effect of surface area on the properties of fine powders. As a result, much support and encouragement has been extended to researchers working in the field of fine particle technology. It was such support as that given by the rubber industry, to which the surface area of carbon blacks is of tremendous importance, that led to the development of the electron microscope; and it was interest in the properties of catalysts, notably that of the oil industry, that was largely responsible for the development of a gas adsorption technique for measuring the surface area of particulate materials.

However, the rubber and oil industries by no means constitute a majority of those industries whose products or processes in some way depend on the surface area of powdered materials. Adsorption, a function of surface area and other characteristics, is widely used in many industrial processes; for example, the properties of coals have been related to their internal surface area, and both the setting time and the power required for pulverizing a cement are dependent upon its surface area.

This increasing importance of powdered materials has made it imperative that a critical review be made of available methods of measuring the surface area of fine particles, in order to determine the best methods for certain types of applications and to develop, where necessary, other measurement techniques. This task has been undertaken at Georgia Tech.

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SURFACE STRUCTURE

Many particulate materials, such as quartz sand, are dense solids, whereas other materials, such as activated charcoal, are permeated by a labyrinth of exceedingly fine capillaries. That portion of the total surface area contributed by the walls of these capillaries is called internal surface area, and the remaining area is called external surface area. Properties such as the catalytic activity and adsorptivity of powdered materials when used in connection with gaseous systems depend on the total of both the internal and external surface areas of the powdered material, because gases are usually able to penetrate even the smallest capillaries. However, the setting of cement is brought about by a reaction occurring at the points of contact of the individual cement particles; hence, this property is primarily dependent on external surface area. The removal of the organic coloring material from sugar syrups by adsorption on bone char is a process involving the external surface area and only a portion of the internal surface area, since the large organic color molecules are too large to penetrate many of the finer capillaries. Therefore, the surface area of a particulate material of interest in any process is largely dependent upon the use for which the material is intended.

MEASUREMENT METHODS

Many methods have been devised for measuring surface area, but most of these are subject to limitations. Light extinction methods, such as the Wagner turbidimeter, are unsatisfactory because the laws governing the situation differ, depending on whether the particles are larger or smaller than the wave length of the light. Gen-

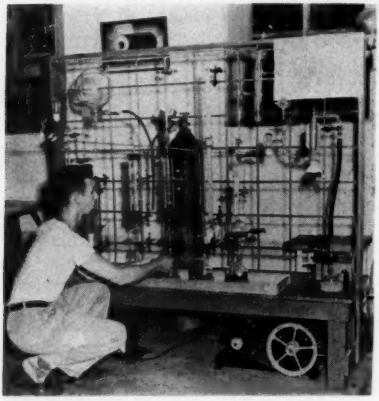

Figure 1. Gas adsorption apparatus.

erally, mixtures of particles range in size from below the wave length of white light to well above it. Air-elutriation and liquid-sedimentation methods are indirect approaches to surface area measurement. They depend on a determination of the particle size distribution, from which the surface area must be calculated by assuming some particular particle shape. Air-elutriation methods are slow and require that the material be of uniform density; liquid-sedimentation methods give dubious results for particles below five microns in diameter unless elaborate precautions are taken to eliminate thermal and mechanical convection currents. Furthermore, the aforementioned methods depend for accuracy on complete dispersion of the material, so that the particles are distinct and separate.

The optical microscopic measurement method, i.e., actual measurement of particle diameters with an optical micrometer, is suitable only when the particles are larger than about 0.5 micron in diameter and relatively uniform in size and shape. If an electron microscope is used for particle size measurement, much time and effort is often required. In general, whether optical or electron microscope measurement techniques are used, the linear measurements obtained must be converted to surface measurements, and this cannot be done except on a relative basis, since the surface shape factors of the particles must be known. The above methods at best only give a qualitative measure of external surface area.

Analyses for determining both the internal and external surface area by measuring the rate of chemical reaction are difficult to perform, and it is doubtful if they actually measure surface area. Similarly, heat of wetting methods require careful experimentation. The latter do measure internal as well as external surface area, but they are entirely unsuitable for routine measurements in their present state of development.

PERMEABILITY MEASUREMENT

The permeability method of surface measurement is based on the flow of a fluid, usually air, through a bed of the material whose surface is to be measured. For particles larger in diameter than about 0.5 micron, this procedure yields reliable results. The apparatus employed is simple; it consists essentially of a chamber in which the bed of material is formed, a manometer for measuring the pressure drop across this bed when a fluid is flowing through the bed, and a calibrated orifice and manometer for measuring the rate of flow.

The mathematical relation which describes the flow through a bed of fine material is based on the well-known Hagen-Poiseville equation for flow through a single capillary channel, considering the bed of finely divided material as presenting a multitude of capillary channels. However, when the capillary channels are less than about 0.5 micron in diameter, which occurs when the individual particles are of about that size, diffusion (i.e., flow due to the random motion of the individual molecules composing the gas stream) becomes of importance, and the mathematical relations describing the conditions in this case are at present unknown. The permeability method, of course, measures the external surface area only, and consequently has proved quite satisfactory for correlating the properties of cements.

ADSORPTION METHODS

Adsorption methods are based on the adsorption of either gases or of solutes from the liquid phase. S. Brunauer, P. H.

Emmett, and E. Teller* have developed a very accurate method, the so-called BET method, for determining surface area from gas adsorption data (the previously mentioned development based largely on the result of catalyst studies). The apparatus (the one in use at Georgia Tech is shown in Figure 1) and experimental technique for making the actual surface area determination are far from simple, however. Basically, the method involves the determination of the quantity of a gas necessary to form a monomolecular layer on the surface of the material whose surface area is to be measured. By determining the number of molecules required to form this layer and applying knowledge of the area covered by one molecule, the surface area of the material is calculated as the product of the two factors.

All solid materials which have been exposed to the atmosphere have considerable quantities of nitrogen, oxygen, and water vapor adsorbed on their surfaces. The first step in the surface area determination by the gas adsorption method is to drive off these adsorbed substances by heating and at the same time evacuating the space about the sample of material. When the sample and sample space are sufficiently (relatively completely) evacuated, the sample is cooled to the temperature of liquid nitrogen (−320° F.), a small quantity of gaseous nitrogen is admitted to the sample, and by noting the pressure changes, the quantity of gas adsorbed is obtained.

As additional quantities of gas are admitted to the sample, a change in the ability of the sample to adsorb the gas is eventually detected; the conditions at which this change occurs are most easily determined by plotting the experimental data as shown in Figure 2 for a carbon black on which nitrogen gas was adsorbed. Several types of evidence indicate that the straight-line portion of the curve represents the piling-up of adsorbed molecules on each other, or that the condition at which the straight-line portion of the curve begins is that at which only a single layer of adsorbed molecules is present. The adsorption portion of the experiment is carried out at the temperature of liquid nitrogen because the surface area occupied by a nitrogen molecule is most accurately known at this temperature. This gas adsorption method measures the total surface area of particulate materials, and has been used with considerable success in studies of catalytic activity.

*S. Brunauer, P. H. Emmett, and E. Teller, "Adsorption of Gases in Multimolecular Layers," *J. Amer. Chem. Soc. 60*, 309-19 (1938).

DYE ADSORPTION

A dye adsorption technique now in a preliminary stage of development at Georgia Tech is in some respects similar to the BET method, but the determination is made in the liquid phase, and the molecules which are adsorbed are of much larger size. They are therefore unable to penetrate many of the microcapillaries which are readily accessible to gas molecules, but, by using dye molecules of various sizes (there being a wide variety from which to select), it is anticipated that much can be learned about

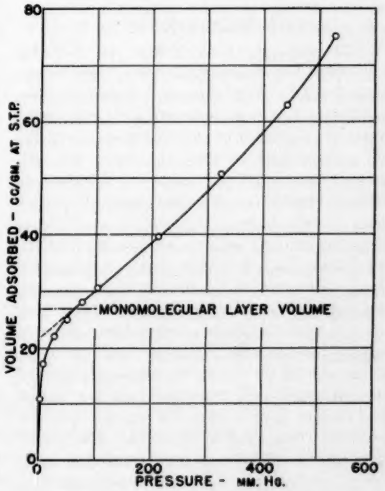

Figure 2. The adsorption of nitrogen gas by carbon black at the temperature of liquid nitrogen. This method of plotting experimental gas adsorption data reveals the condition at which the gas is present as an adsorbed layer one molecule thick.

the size and distribution of the microcapillaries in many materials.

The material whose surface area is to be measured is exposed to dye solutions of increasing concentration until a change in the capacity of the material to adsorb the dye is detected by the expedient of plotting the experimental results as shown in Figure 3. Reasoning similar to that used in arriving at the selection of the lower extremity of the straight-line segment in a plot of the experimental gas adsorption data as the condition at which an adsorbed monomolecular gas layer was present leads to a similar conclusion in the case of dye adsorption results. The surface area of the material on which the dye was adsorbed is then calculated by multiplying the number of molecules of dye required to form the monomolecular layer by the area covered by one dye molecule. Malachite green oxalate is the dye which has been used in most of the investigations to date; its concentration in solutions is determined colorimetrically.

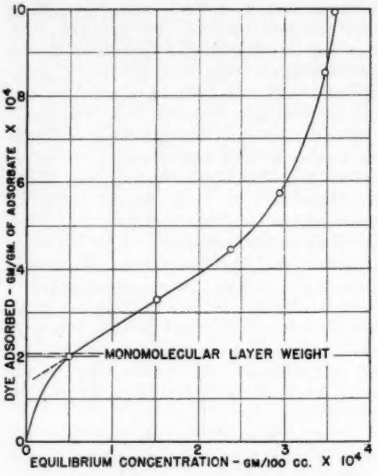

Figure 3. The adsorption of malachite green oxalate by quartz sand. This procedure for treating experimental data establishes the quantity of dye necessary to form a layer of dye molecules one molecule deep on the surface of the adsorbent.

COMPARATIVE DATA

The permeability and the gas and dye adsorption methods give surface area values which are in relatively close agreement for materials which have little or no internal surface area, such as the first three in Table I. Results such as those for halloysite, the fourth material in Table I, indicate of course that much of the internal surface area of halloysite is due to the walls of microcapillaries which are less than about 15 Å in diameter, which is the approximate diameter of the malachite green molecule. Certain activated charcoals may have a total surface area as great as 10,000,000 cm.²/gm. (approximately one quarter of an acre), most of which is attributable to the walls of the very small microcapillaries which permeate each charcoal grain.

It is obvious from the data given in Table I that there are wide discrepancies in results obtainable from the three methods used here for the measurement of surface area. Each method measures some kind of a surface, and each requires proper interpre-

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TABLE I

SURFACE AREA VALUES DETERMINED BY THREE METHODS

Material	Surface Area (cm.²/gm.) Measured By		
	Gas Adsorption	Dye Adsorption	Permeametry
Nylon fiber	1,600	1,300	500
Quartz sand	6,000	3,500	2,500
Copper	3,000	1,600	2,400
Halloysite	87,200	3,000	700

WGST-FM

By BEN AKERMAN* *and* M. A. HONNELL**

Georgia Tech has long been closely associated with electronic research in the field of radio broadcasting, often in close connection with its commercial station WGST. The following article briefly describes the operations of WGST-FM, whose location, etc., were determined by studies in which the Engineering Experiment Station cooperated.

Since July 17, 1949, Radio Station WGST-FM has been providing FM listener coverage over most of Georgia and large sections of contiguous states on a frequency of 94.1 megacycles. This excellent coverage has been achieved because of the favorable location of the FM transmitter on top of Burnt Mountain, 52 miles north of Atlanta near Jasper, Georgia. Selection of this mountain site was made after an extensive survey by WGST, during the war, for a suitable location for regional coverage by an FM station.

GEORGIA TECH STUDIES

In connection with this study of FM propagation in the Atlanta area,*** the Georgia Tech Engineering Experiment Station operated a one-kilowatt developmental broadcast FM station, W4XAG, on the Georgia Tech campus from 1945 to 1948.

*Chief Engineer, Radio Station WGST.
**Professor of Electrical Engineering.
***M. A. Honnell, "FM Propagation Survey of the Atlanta Area." *The Research Engineer 1947-1948*, No. 3, 3, 4, 17-20 (November, 1947).

Figure 1. The WGST-FM transmitter building on Burnt Mountain. Note the receiving parabolic antenna near the base of the FM tower.

Then, in 1948, this transmitter was transferred to WGST and was installed at the AM transmitter house near Cheshire Bridge Road on the outskirts of Atlanta, going on the air as WGST-FM. This transmitter is still kept in operating condition to serve as an emergency transmitter in the event that the mountain installation fails completely.

In August, 1946, WGST decided to set up a transmitter on Burnt Mountain, on property under option, in order to determine if it were feasible to cover Atlanta from this location. Field tests were then conducted as joint projects of the Georgia Tech Engineering Experiment Station and WGST. In connection with these studies, an 80-watt portable FM transmitter was constructed for operation in a panel truck completely equipped with a gasoline-driven generator and the other accessories necessary for operation at remote locations. The portable FM station was set up on the top of Burnt Mountain with call letters WMNK and was operated for several days by the WGST engineers, while the Engineering Experiment Station's field car made continuous recordings of field intensity along highways leading into Atlanta, Rome, Chattanooga, and other population centers.

These tests indicated that an FM station of suitable power on top of Burnt Mountain would blanket Atlanta with a field intensity of 5000 microvolts per meter and would render reliable service as far south as Macon. The transmitter site finally selected is 3,330 feet above sea level.

The average elevation from Atlanta to a few miles from Burnt Mountain is a little less than 1000 feet. However, an FM transmitter site cannot be chosen solely on the basis of high elevation. Available facilities are equally important. The location se-

lected was formerly occupied by the Connahaynee Lodge, which burned several years ago. The road, water supply, telephone line, and power line used by the hotel were therefore available for use by WGST.

DESCRIPTION OF STATION

As soon as the Federal Communications Commission granted a construction permit for the FM station, a building 28 by 72 feet was erected of Steelox prefabricated construction insulated with rock wool and placed over concrete floors covered with asphalt tile. This building, shown in Figure 1, has complete living quarters for four operating engineers.

The antenna system employed consists of a General Electric eight-bay antenna containing sleet melting equipment, mounted on a Blaw Knox tower 165 feet high. The over-all height of the antenna system is 245 feet. By directing the radiated energy along a horizontal plane, this antenna gives the FM transmitter an equivalent power gain of seven.

The General Electric transmitter installation consists of a 250-watt exciter unit employing Phasitron modulation, followed by a three-kilowatt amplifier unit driving a ten-kilowatt final amplifier. The effective radiated power, including the antenna gain, is 70 kilowatts. Dual transcription turntables are provided at the transmitter for test and emergency program service.

The power demand of the entire installation is approximately 30 kilowatts. Since power failures are frequent in remote mountainous country during the winter, a Diesel standby plant having an output of 55 kilowatts at 220-volts three-phase has been installed for emergency use; sufficient oil is stored to operate this plant for 20 days. Oil is also used to heat the building during the winter. Since the transmitter generates 15 kilowatts of heat, this heat is also fed into the building during cold weather and is "dumped" outdoors during the summer.

The cost of a telephone line of FM-broadcast quality from the WGST studios in the Forsyth Building in downtown Atlanta to the Burnt Mountain installation would be prohibitive. Programs are therefore beamed with a six-foot parabolic antenna from the roof of the Forsyth Building to a similar antenna mounted on the transmitter tower 52 miles distant; the receiving parabola may be noted in Figure 1. This radio link system has over-all noise and distortion characteristics which are superior to those of the over-all FM broadcasting system. The frequency-modulated radio link transmitter has a power output of ten watts on a frequency of 949.5 megacycles. However, the directional transmitting and receiving antennas, which have an over-all gain of 34 decibels, give an equivalent power gain of 2,500. The link receiver consists of a standard REL 112-megacycle crystal-controlled FM receiver with a converter which employs a temperature-controlled crystal oscillator followed by several frequency multiplying amplifiers. The fidelity of this radio link, incidentally, is superior to the service available on a line wire circuit. The only telephone connection employed is one with Jasper, used for message purposes.

AREA COVERAGE

Area coverage by WGST-FM is highly satisfactory. Reports of consistent reception have been received from Alabama, Tennessee, Kentucky, South Carolina, North Carolina, and Virginia. Reception is good enough for rebroadcast by most radio stations in Georgia north of Macon. WGST-FM provides excellent day and night program service, from 5:30 A. M. to 10:30 P. M., to a vast rural area that does not receive adequate radio service from other radio stations, because of the limitations of AM broadcasting.

People living in cities such as Atlanta, in which reliable AM reception is available from several stations, are often relatively indifferent to the merits of an FM program source. Anyone living in rural areas "down South," however, realizes full well that static and distant stations often cause disagreeable interference in the standard AM band. One of the major advantages of a service such as that rendered by WGST-FM is that it provides consistent day and night coverage of a vast area with freedom from static and interference from other FM stations. As the general public gradually becomes more aware of this fact, FM audiences will grow at an accelerated pace.

DIGEST OF GRADUATE THESES

MECHANICAL ENGINEERING

1948-1949

The following digests represent summaries of theses submitted during 1948-1949 in partial fulfillment of the requirements for the degree of Master of Science in Mechanical Engineering. This is the fourth in a series of features designed to present data on the graduate theses submitted last year to the various schools of the Georgia Institute of Technology.

Chia-San Chou. *A Study of Heat Transfer Involving a Gas with Suspended Particles.* Faculty advisor: Professor M. J. Goglia.

The study reported in this thesis was concerned, in view of problems connected with the development of a coal-burning gas-turbine power plant for locomotive use, with designing a device for cooling hot ashes. In the necessary understanding of the mechanism of the resulting heat transfer and criteria affecting the inter-relation between aspirated cold air and the hot gas stream conveying the suspended hot ash particles, particular consideration must be given four factors: the design of a convergent nozzle passing a gas with suspended particles; the theory of the simple ejector; the motion of particles in a conveying stream; and heat transfer from the particles.

Analysis gave evidence that, although gas velocity and flow rate through a nozzle decreases as the ash-gas ratio increases, an ash-gas weight ratio of 1:20 produces an inappreciable effect. In order to attain the high velocity of particles relative to gases, which is desirable for best mixing of the hot-ash-particle stream and the cold air, the primary nozzle ejecting the hot stream should be short. A diffuser section following the constant-area mixing tube facilitates maintenance of a high relative velocity between gas and particles and, consequently, will improve the total heat transfer. *M.M.*

George Frederick Epps. *Correlation of Flame Density and Knock Intensity.* Faculty advisor: Professor R. L. Allen.

Examination of the historical background of detonation in internal combusion engines reveals no really satisfactory explanation of that phenomenon. However, progress in this direction might be made if correlation could be discovered between the density of the combustion flame and the intensity of knock.

It was believed that the operation of a CFR Engine under varied knocking conditions might yield data from which the density of the flame of combustion could be calculated. Graphed experimental results of tests conducted by operating a CFR Engine under varied knocking conditions indicated that knock density decreases as flame density increases. A more exact determination of this correlation should be attempted, with a view toward control of the factors affecting flame density in order to decrease knock intensity. *M.M.*

Robert Lee Newell. *Lubrication and Power Characteristics of the Textile Spindle.* Faculty advisor: Professor R. L. Allen.

In the production of textiles, power is one of the most important items bearing on the manufacturing cost. Spinning rooms usually consume about 60 per cent of the total power, and spindles use the greatest portion of this. Although lubrication of spindles to prevent wear has been successful for many years, greater reduction in power consumed should be possible with improved lubrication.

The purpose of the investigation presented in this thesis was to determine the possiblility of gaining worthwhile power savings by using oils of lower than usual viscosities on the average spindle and to present data on the general power characteristics and other variables of the textile spindle. It was found that the power required for driving a spindle increases with its speed and with size or volume of the package employed and decreases with de-

crease in viscosity of the spindle oil used. Power reductions by use of lower viscosity oils were found to be worthwhile and to represent one of the simplest methods of reducing power costs.

A dynamometer capable of making checks on the small amounts of power required by a single spindle was designed and its application in any textile research department described. *A.S.C.*

Grover Cleveland Robinson, Jr., *An Investigation of the Formation of Cavitation About Modified Cylindrical Models.* Faculty advisor: Professor R. L. Allen.

Experimentation conducted in an effort to overcome the pitting which results from cavitation action has been supplemented only recently by an investigation of the complete life history of cavities. Because of disagreement among authorities concerned with this engineering problem, it was decided that a detailed study of the formation and collapse of cavitation bubbles should be made.

Experiments were conducted in a pilot model of a variable-pressure water tunnel designed by Professor C. E. Kindsvater. In calculations based on Thoma's cavitation parameter, the incipient cavitation number was taken as that condition at which cavitation is first visible. Comparisons of four models, each with a different combination of nose and afterbody, indicated that the afterbody influenced neither the point of incipient cavitation nor the cavitation envelope. However, the bevelled nose caused a lower cavitation number than the blunt nose, and, at equal cavitation parameters, the envelope volume of the bevelled-nose models is less than that of the blunt-nose models. *M.M.*

Harry Carter Robinson, Jr., *Study of the Efficiencies and the Relative Merits of Convection and Radiant Heating Systems.* Faculty advisor: Professor Howard W. Mason.

Knowledge of heating systems is of paramount interest to the heating engineer from the standpoints of economy, comfort, relative humidity, actual temperatures, mean radiant temperatures, and surface temperatures. The investigations described in this thesis were conducted in one building which had both a radiant and a convection heating system. Data were correlated by simultaneous readings in the two systems under conditions as nearly identical as possible.

Panel heating (misnamed radiant heating) systems were found to have many advantages over convection systems. They operate at a lower dry bulb temperature and have more desirable temperature gradients than the convection-heated rooms. Panel heating systems take up no floor space and will not cause streaks on walls, as often happens when convective currents rise. A major disadvantage of panel heating is the lack of completely independent control of the room temperature in multistory buildings, because the overhead panels which heat the room above and the room below are controlled only by valves on the floor above. Another panel disadvantage is the marked thermal lag in the control of the system. Although neither system provides control of moisture, the relative humidities of the two systems encountered during this investigation were within the comfort zone. *A.S.C.*

Frank Almerine Thomas, Jr., *A Study of the Flow of Air into Plane Obstructed Openings.* Faculty advisor: Dr. J. M. Dalla Valle.

Many devices have been used in industry for the control of gases, dust, and other airborne substances. The "canopy hood" is the most widely used type of exhaust hood because of its simplicity and low cost, but it has some limitations, which form the basis of the investigations evolved in this thesis.

Studies were made of air flow into three configurations, round, square, and rectangular obstructed openings, by using the method of determining point velocities employed by DallaValle, that is, with a cylindrical tube and Wahlen gage (a differential micromanometer). The air velocities obtained over a range of 50 to 1,500 f.p.m. were plotted for each unit interval from the opening as percentages of the average face velocity against distance above the boundary of the hood; then these curves were translated to velocity contours for the particular opening. It was found that the obstruction had much influence on the velocity contours when its distance from the opening was less than one half of the hood diameter; however, the effect of the obstruction was negligible when at a distance greater than three-fourths the hood diameter. *A.S.C.*

REPORT FROM THE LIBRARY

By DOROTHY M. CROSLAND*

The Georgia Tech Library is continuing to add to its accessions of periodicals and transactions of scientific and technical societies. The following article lists some of the recent additions.

We have had innumerable requests for lists of the periodicals that are in the Georgia Tech Library. Therefore, several months ago we started compiling a list which would include our holdings both of periodicals and transactions of scientific and technical societies. Actually, this list will contain our serial holdings, not only of current titles but of our complete holdings. Because of a shortage of staff and space, however, we have been "bogged down." Nevertheless, we do hope to have this list finished by the spring of 1950, and it will then be published as a Bulletin or Special Report of the Engineering Experiment Station. We feel that such a complete list of our serial holdings will be of value to the research workers of this region.

During the past year we have added many new titles to our collection, and we think that those of you who read THE RESEARCH ENGINEER will be interested in our acquisitions in the periodical field. We hope to complete our files of all of these as soon as we can locate missing volumes. Copies of most scientific and technical journals are scarce, however. After many first printings, publishers cannot supply even one issue. That means that we must attempt to get missing issues from second hand dealers. This takes months, sometimes years. In some instances we shall have to fill in our gaps with photostatic copies or microfilms. All this is part of our attempt to build a reservoir of engineering and scientific library materials.

The new periodicals in our library are as follow:

Acta Crystallographia. Cambridge, England, v. 1, Mar. 1, 1948-.
Advancement of Science. London, v. 5, No. 20, Jan., 1949-.
Aeronautical Quarterly. London, v. 1, May, 1949-.
Air Affairs. Falls Church, Virginia, v. 1, 1946-.
Akademiia Nauk, SSSR. Comptes Rendus (Doklady) de L'Academie des Sciences de L'URSS. Leningrad, v. 64, new series, Jan., 1949-.

*Librarian, Georgia Institute of Technology.

Akademiia Nauk, SSSR. Izvestiia, Serna Biologicheskaia. Leningrad, Jan., 1949-.
Akademiia Nauk, SSSR. Izvestiia. Seriia Fizicheskaia. Leningrad, v. 13, Mar., 1949-.
Akademiia Nauk, SSSR. Izvestiia. Otdelenie Khimicheskikh Nauk. Leningrad, Jan., 1949-.
Akademiia Nauk, SSSR. Izvestiia. Otdelenie Matematicheskikh . . . Seriia Matematicheskaia. Leningrad, v. 13, Jan., 1949-.
Akademiia Nauk, SSSR. Izvestiia. Otdelenie Tekhnicheskikh Nauk. Leningrad, Jan., 1949-.
Annales des Telecommunications. Paris, v. 1, 1946-.
Annali di Chimica Applicata. Rome, v. 39, Jan., 1949-.
Annual Review of Microbiology. Stanford, California, v. 1, 1947-.
Applied Hydraulics. Cleveland, v. 1, 1948-.
Applied Mechanics Reviews. Easton, Pennsylvania, v. 1, Jan., 1948-.
Architect's Journal. London, v. 109, Jan., 1949-.
Architecture. Sydney, Australia, v. 37, Jan., 1949-.
Archiv der Mathematik. Karlsruke, Germany, v. 1, 1948-.
Archiv fur Metallkunde (Continuation of *Korrosion und Metallschutz*). Weinheim, Germany, v. 2, Jan., 1948-.
Archives des Sciences Physiques et Naturelles. Geneva, v. 2, Mar., 1949-.
Australian Official Journal of Patents, Trademarks, and Designs. Canberra, Australia, v. 18, Jan., 1949-.
Australian Plastics. Sydney, Australia, v. 2, No. 14, June, 1946-.
Bauplanung und Bautechnik. Berlin, v. 1, July, 1947-.
British Journal of Industrial Medicine. London, v. 2, Jan., 1945-.
British Rayon and Silk Journal. Manchester, England, v. 26, No. 298, Mar., 1949-.
Brookhaven National Laboratory Weekly Selected Reading List. Brookhaven, Massachusetts, v. 1, Jan., 1949-.

Canadian Journal of Mathematics. Toronto, v. 1, Jan., 1949-.
Canadian Plastics. Toronto, v. 7, Sept., 1949.
Ceramic Digest. London, v. 1, 1947-.
Chemie-Ingenieur-Technik. Zeitschrift fuer alle Gebiete der Chemischen Technik und des Chemie-Engenieurwessens (Formerly Abteilung B of *Angewandte Chemie*). Weinheim, Germany, v. 21, Jan., 1949-.
Chemistry. New York, v. 22, Sept., 1948.
Chemurgic Digest. Columbus, Ohio, v. 8, Jan., 1949-.
Econometrica. Chicago, v. 17, Jan., 1949-.
Electricite. Paris, v. 33, No. 146, Jan., 1949-.
Electronic Engineering. London, v. 20, No. 239, Jan., 1948-.
Electroplating and Metal Finishing. London, v. 2, Jan., 1949-.
Elecktron in Wissenschaft und Technik. Munich, v. 3, Jan., 1949-.
Elemente der Mathematik. Basel, Switzerland, v. 4, Jan., 1949-.
Fibres. London, v. 10, Jan., 1949-.
Guide to Russian Scientific Periodical Literature. Oak Ridge, Tennessee, v. 1, Jan., 1948-.
La Houille Blanche: Revue de L'Ingenieur Hydraulicien. Paris, v. 4, 1949-.
Indian Academy of Science. Proceedings A and B, Bangalore City, India, Series A, v. 1, 1934-; Series B, v. 1, 1934-.
Industrial Psychology and Personnel Practice. Melbourne, Australia, v. 5, Jan., 1949-.
Industrie des Plastiques Modernes. Paris, v. 1, 1949-.
Institution of Sanitary Engineers Journal. London, v. 45, No. 5, Jan., 1946-.
Institution of Water Engineers Journal. London, v. 51, 1946-.
Irish Radio and Electrical Journal. Dublin, v. 6, No. 73, Mar., 1949-.
Journal of Geophysical Research (continues *Terrestrial Magnetism and Atmospheric Electricity*). Baltimore, v. 54, Mar., 1949-.
Journal of Metals. New York, v. 1, Jan., 1949-.
Journal of Petroleum Technology. New York, v. 1, Jan., 1949-.
Journal of Southern Research (formerly *Journal of Southeastern Research*). Atlanta, v. 1, Jan., 1949-.
Kolloidnyi Zhurnal. Akademiia Nauk SSSR, Moscow, v. 11, Jan., 1949-.
Light Metals Bulletin. London, v. 11, new series, Jan., 1949-.
Marconi Review. London, v. 10, Jan., 1947-.
Matematisk Tidsskrift. Kopenhaven, Denmark, A, 1949-; B (Advanced) 1949-.
Microtechnic. Lausanne, Switzerland, v. 1, Feb., 1947-.
Mikroskopie; Zentralblatt fur Mikroskopische Forschung und Methodik. Vienna, v. 1, Aug., 1946-.
Midwest Engineer. Evanston, Illinois, v. 1, Sept., 1948-.
Mining Engineering. New York, v. 1, Jan., 1949-.
Nature. Paris, v. 77, No. 3165, Jan., 1949-.
Optik. Stuttgart, v. 1, Jan., 1946-.
Osterreichische Zeitschrift fur Telegraphen-Telephonfunk- und Fernsehtechnik. Vienna, v. 3, Jan., 1949-.
Das Papier. Darmstudt, Germany, v. 1, July, 1947-.
Physics Today. American Institute of Physics, Lancaster, Pennsylvania, v. 1, May, 1948-.
Prevention of Deterioration Abstracts. Washington, D. C., v. 1, 1946-.
Prikladnaia Matematika i Mekhanika. Leningrad, v. 13, Jan., 1949-.
Quarterly Reviews. London, v. 1, 1947-.
Radiotekhnika. Moscow, v. 4, Jan., 1949-.
Revue Scientifique. Paris, v. 86, No. 3288, Jan., 1948-.
Ricerca Scientifica. Rome, v. 19, Jan., 1949-.
Rocket Science. Detroit, v. 2, Mar., 1948-.
Royal Statistical Society Journal. Series A (General), London, v. 112, 1949-.
Schweizerische Technische Zeitschrift. Bern, Switzerland, v. 46, Jan., 1949-.
Science and Culture. Calcutta, v. 11, 1946-; v. 12, 1947 (incomplete).
Scientia. Valparaiso, v. 15, Mar., 1948-.
Society of Architectural Historians Journal. Urbana, Illinois, v. 5, 1945-46-.
South African Electrical Review. Johannesburg, S. Af., v. 37, Mar., 1946-.
Standards World. Washington, D. C., v. 1, Aug., 1948-.
Suomen Kemistilehti. Helsingsfors, Finland, v. 22, 1949-.
Tekstil'naya Prom-Ishlennost. Moscow, v. 9, Jan., 1949-.
Textielwezen. Ghent, Belgium, v. 5, Jan., 1949-.
Textil-Rundschau. St. Gallen, Switzerland, v. 1, July, 1946-.
Textiles Suisses. Lausanne, Switzerland, No. 2, Feb., 1949-.
Town Planning Review. Liverpool, v. 20, Apr., 1949-.
Travail et Methodes. Paris, v. 1, 1948-.
Universite de Paris. Institut Henri Poincare. Annales. Paris, v. 11, Jan., 1949.
Uspekhi Fizicheskikh Nauk. Moscow, v. 37, Jan., 1949-.
Uspekhi Khimil. Moscow, v. 18, Jan., 1949-.
Uspekhi Matematicheskikh Nauk. Moscow, v. 4, Jan., 1949-.
Weather. London, v. 1, May, 1946-.
Werk, Die Schweizer Monatschrift fur Architekt Kunst und Kunstlerisches Gewerbe. Winterthur, Switzerland, v. 36, Jan., 1949-.
Wire and Wire Products. Jersey City, N. J., v. 24, Jan., 1949-.
Wood. Chicago, v. 4, Jan., 1949-.
Zeitschrift fur Erzbergbau und Metallhuttenwesen (Continues *Metall und Erz*). Stuttgart, v. 1, 1948-.
Zhurnal Eksperimental' noi i Teoreticheskoi Fiziki. Moscow, v. 19, Jan., 1949-.
Zhurnal Obshchei Khimii. Moscow, v. 19, Jan., 1949.

PEANUTS AND GEORGIA

Continued from Page 2

oil, packaged salted nuts, peanut candy, and new peanut products; such production must then be aggressively marketed.

To effect economies in growing and processing, better mechanized methods of planting, harvesting, curing, and grading must be developed and applied. The Georgia Tech Engineering Experiment Station is already working closely with the Georgia Agricultural Experiment Station and other agencies in engineering and agricultural research on developing the necessary equipment, and it stands ready to intensify its efforts to help solve aspects of a really pressing problem.

RECENT STATION PUBLICATIONS

The following publications have been released by the Station since those reported in the September, 1949, issue of THE RESEARCH ENGINEER.

CIRCULARS

M. A. Honnell (Editor), *Proceedings of the Broadcast Engineers Conference*, Georgia Institute of Technology, Engineering Experiment Station Circular No. 26, 1949. 82 pages. One dollar.

The proceedings of the second Broadcast Engineers Conference, held in Atlanta in May and jointly sponsored by the Georgia Institute of Technology, the Atlanta Section of the Institute of Radio Engineers, and the Georgia Association of Broadcasters, include 14 of the 15 papers presented at the conference. Three papers deal with recording equipment, two with measurements and designs for high-frequency operation, two with FM equipment, one with design and operation of an AM directional antenna array, one with the resnatron tube, one with use of metallic rectifiers for high voltage supplies, and three with general subjects (problems in program transmission channels; basic buy in television equipment; and trends in standard broadcast, FM, and television).

These proceedings are intended to provide a permanent record of many of the latest developments in the field of broadcast engineering. *A.S.C.*

Georgia Tech Engineering Experiment Station, 1948-1949, Georgia Institute of Technology, Engineering Experiment Station Circular No. 27, 1949. 3 pages. Gratis.

This reprint of an article from the August 22, 1949, issue of *Chemical and Engineering News* describes in considerable detail the 1948-49 project work of the Station in chemical and chemical engineering fields. Under "Methods Research" are listed projects on food freezing, battery studies, water and sewage analysis, cellulose studies, development of vulcanized oil, and wood distillation. Projects classed under "Materials" deal with properties of matter at very low temperatures, nylon staple research, weed killers, clay products, surface properties of fine particles, and food products. "Engineering Design" projects include gasoline engine design, a pressure manometer, and buff problems.

Numerous literature searches were listed under "Technical Information." Miscellaneous projects include graphical methods of calculation and stream survey, heat transfer, and network calculator studies. Details of the Station's growth and general activities are similar to those published in the article on the Station in the September, 1949, issue of THE RESEARCH ENGINEER. *A.S.C.*

REPRINTS

R. S. Ingols, *"Water" Analysis*, Georgia Institute of Technology, Engineering Experiment Station Reprint No. 36, 1949. 4 pages. Twenty-five cents.

This article, reprinted from the October, 1949, issue of *The Filter Press*, presents many of the problems confronted in analyzing water for home consumption, as well as "used waters"—sewages and industrial wastes. Specific techniques of analysis used in the research program conducted at Georgia Tech are described in some detail and include tests for hardness, fluoride ions, oxygen consumed, and Biochemical Oxygen Demand. *A.S.C.*

H. A. Wyckoff, *Coliform Death Rates Resulting from Chlorination of Raw Sewage*, Georgia Institute of Technology, Engineering Experiment Station Reprint No. 35, 1940. Twenty-five cents.

This paper, reprinted from the May, 1949, *Sewage Works Journal*, reports the results of a research project initiated in order to obtain data on the rate of bacterial (coliform) kill in plant-scale chlorination of raw sewage at varying chlorine residuals and for various contact periods. Experimental procedures for chlorination of the sewage, determinations of the Most Probable Number, pH, the chlorine demand, B. O. D., and suspended solids are described, and typical data collected during individual experiments are included and discussed. *A.S.C.*

H. P. Peters, *Load-Adjusting Voltmeters Speed Up Calculator Operation*, Georgia Institute of Technology, Engineering Experiment Station Reprint No. 37, 1949. Gratis.

The a-c network calculator at Georgia Tech is the first large calculator in the country

to utilize all of the time-saving improvements developed for such boards. One of these, the load-adjusting voltmeter, is described in this paper, reprinted from the October 8, 1949, issue of *Electrical World*. This instrument is in effect a voltmeter with an adjustable 50,000-ohm calibrating resistance. On the basis of low cost, ease of installation, and minimum disturbance of the original equipment, the Georgia Tech A-C Network Calculator is probably the best installation of its type to date. *A.S.C.*

W. M. Spicer and W. T. Ziegler. *Spectrochemical Determination of Lanthanum in Praseodymium Metal*, Georgia Institute of Technology, Engineering Experiment Station Reprint No. 38, 1949. 2 pages. Gratis.

The quantitative determination of certain of the rare earths can be conveniently made by spectrophotometric means. However, this method is not applicable in the case of lanthanum because its ion exhibits no suitable absorption band. This paper, reprinted from the November, 1949, issue of *Analytical Chemistry*, describes a spectrographic method of analysis for lanthanum, using the copper spark method with the addition of an internal standard. Details of equipment, photometric procedure, preparation of solutions, and experimental results are given. This method of analysis was checked by use of a known sample and was found to be quite accurate. *A.S.C.*

SURFACE AREA STUDIES

Continued from Page 8

tation. Dye adsorption, everything considered, would be expected to give surface values somewhere between the permeametric and BET methods because the larger molecules of dye cannot enter many of the molecular capillaries. Whatever interpretation is made will in part depend upon the ultimate use to which the material measured will be put. If it is to be used for adsorption, BET data are undoubtedly preferable, perhaps also for use with catalytic materials. For many materials where correlation of surface area with light reflectance or adsorption is required, either the dye or the permeametric methods are probably better adapted. It might be mentioned, however, that the latter method is limited at the present time to use with particles larger than 0.5 micron in diameter.

As mentioned, the objects of the surface studies now in progress at Georgia Tech are (1) the establishment of the limitations of the various techniques described here, methods which are too often used without discrimination, and (2) the evaluation of the conditions under which these techniques may be used to obtain desirable correlation with the properties sought in a given material.

Full utilization of the information obtainable from the measurement methods discussed here, when these methods have been completely explored, will permit prediction with assurance of what can be expected from a given particulate material when employed for a specific purpose, or alternately will permit the selection of the material and particle size which will best meet given requirements. Thus, the experimental fact that grinding charcoal particles one millimeter in diameter to particles less than 0.001 millimeter in diameter increases its adsorptive capacity for gases less than ten per cent, while a similar reduction in particle size increases many fold its capacity to decolorize liquid solutions containing organic coloring matter, would have been readily predictable, for charcoals have been found to be permeameted by a myriad of microcapillaries into which gas molecules readily diffuse, but which are too small for large organic molecules to enter. In other words, gaseous adsorption depends on the total surface area, which is little changed by grinding in the case of charcoal, while the adsorption of large organic molecules depends greatly on the external surface area, which *is* affected by grinding.

Consequently, when a gas is to be adsorbed upon passage through a tower packed with an adsorbent material, the use of relatively coarse grains of the adsorbent material offers definite advantages, such as the avoidance of dusting and high pressure drop, without accompanying adsorptive capacity disadvantages, while the use of fine particles for adsorption from liquids is ad-

vantageous in that the adsorption capacity and rate are greatly increased without concomitant disadvantages. These are results which can be fully exploited and which serve here (as a relatively simple example of the possibilities inherent in a greater understanding of the construction of many particulate materials) to show what may be expected when the field of fine particle technology is more fully developed.

ACKNOWLEDGMENT

The studies reported here were supported in part by Contract No. W36-039-sc-38258 with the United States Army Signal Corps Engineering Laboratory.

WATER AND SUPERSONIC AERODYNAMICS

Continued from Page 4

channel, the measurement of local water depths is more complicated and perhaps somewhat inaccurate. North American Aviation, however, feels that the freedom from choking, experienced with the other type of water channel, is well worth overcoming the local depth measurement problem. The North American type of channel requires less refinement than the other type, which necessitates use of many of the special and expensive features of a wind tunnel in order to insure a smooth, uniform flow.

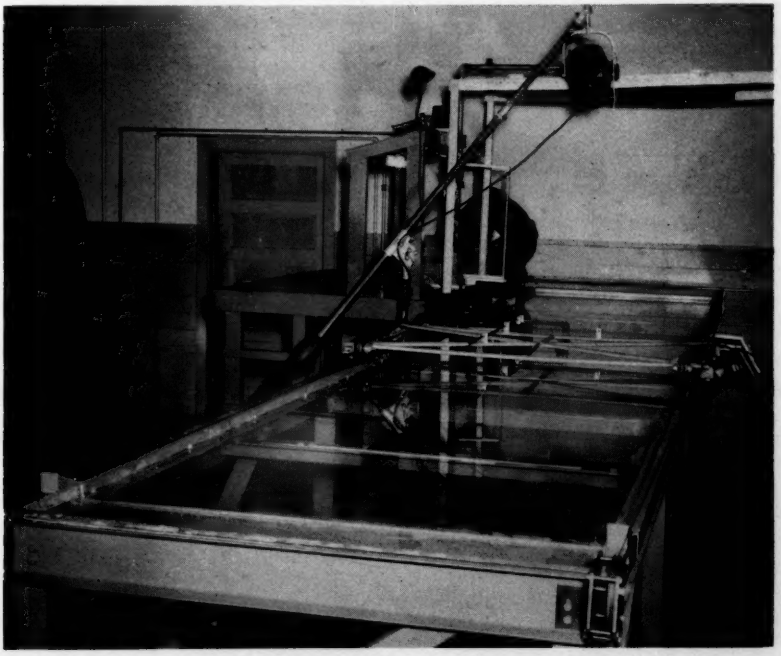

Figure 1. The Georgia Tech 20 ft. x 4 ft. water channel.

GEORGIA TECH CHANNEL

The Georgia Tech 20 ft. x 4 ft. water channel is located in the Daniel Guggenheim School of Aeronautical Engineering. Similar to the channel constructed by North American Aviation, the Georgia Tech water channel is principally a structural steel framework supporting a plate glass surface, which in turn supports the water (Figure 1). A carriage which uses side rails of the water channel for tracks draws a model through the water along the length of the channel. This carriage is driven through an endless cable system and powered by a 1/4-horsepower electric motor to which is connected a "Speed-Ranger" device to provide the desired speed control.

In the test section, two cameras are employed to record the flow about the model, with appropriate illumination and with timing by micro-switches and solonoids. One camera views the test field from overhead, while the other records the side view and hence the variation of water depth along the profile. The schematic diagram shown in Figure 2 demonstrates the test section arrangement.

As stated previously, models used must be two-dimensional. In view of the shallow water, it is not necessary for these models to be more than two inches high. Some of the airfoil models which have been tested are illustrated in Figure 3.

It has been learned that it is desirable to use models more than 12 inches long. It appears that the longitudinal extent of the bow wave is always the same, regardless of the length of the model. Since the disturbance at the bow wave region, and hence the ratio there of local depth to stagnation depth, does not have an analogous relation to the bow or leading edge conditions of the airfoil in the gas flow, it is desirable to limit the bow wave region to as small a per cent of total model length as is possible. North American Aviation[5] tested models which were three and four feet long.

Georgia Tech researchers have also used the water table to study the flow conditions in a supersonic wind tunnel. A full-scale model of a supersonic wind tunnel was constructed (as shown in the top view of Figure 6) and tested in the water channel.

The airfoil models shown in Figure 3 were selected because they had been previously tested in supersonic wind tunnels. It is hoped that these models will serve to establish the quantitative calibration of the water channel and, assuming this confirmation, to reassure the research worker when he uses the water channel to study the aerodynamic properties of shapes that have

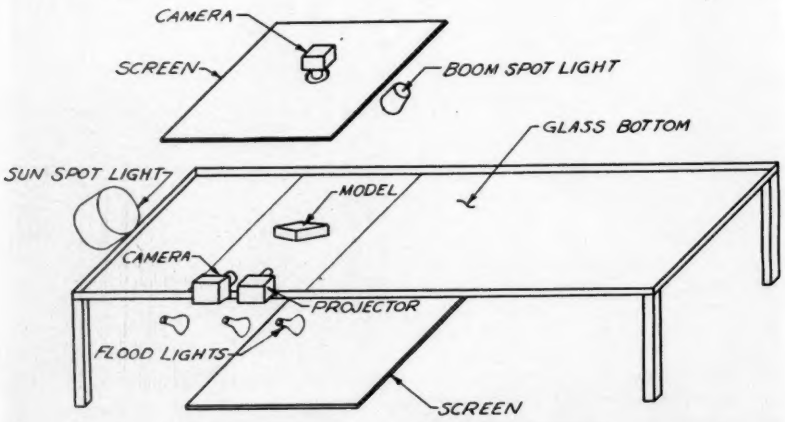

Figure 2. Schematic diagram of water channel and lighting equipment.

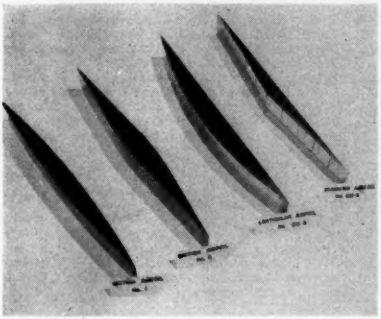

Figure 3. Airfoil models for use in the 12-inch water channel.

not been tested before; also, to inspire confidence in data obtained in the cases of shapes that are not amenable to theoretical analytical methods. A representative view of the overhead record pictures (for models shown in Figure 3) is presented at the top of Figure 4, while the companion side view (bottom of Figure 4) shows the variation of water depth along the model profile.

The overhead view is interesting to the observer because of the startling similarity to the type of picture taken by Schlieren apparatus used to visualize flow conditions in the supersonic wind tunnel (as in the bottom view of Figure 6). This overhead view is used primarily in the construction of velocity distribution surveys and diagrams showing the distribution of lines of constant Mach Number about the model.

The side photograph is of the most value in obtaining quantitative pressure and velocity distribution data from the water channel. In recent tests comparing wind tunnel and water channel test results with the model of a G.U.-3 airfoil at Mach Number $M = 2.13$, good qualitative reproduction of the pressure distribution was obtained by direct application of the hydraulic analogy to water channel test results. Quantitative agreement with wind tunnel test results was obtained after applying a correction to water channel results to account for the meniscus effect between water and model surface. A study of test results revealed that when local water depth is rising, one value of meniscus correction is required, while, similarly, when local depth is falling, another value is required. Some further work in establishing the quantitative aspects of meniscus correction is in progress. Figure 5 shows the comparison of water-channel-obtained pressure distributions for airfoil G.U.-3 and that obtained by Ferri at $M = 2.13$ in the Guidonia Wind Tunnel in Italy.

Water channel tests of the model supersonic wind tunnel demonstrated excellent agreement with studies of the same tunnel shape with air flowing through. The water channel revealed local malformations which disturbed the flow in the same manner as were later observed in the wind tunnel. The net result of this study is that the water channel will serve as an inexpensive means of developing the proper contours for a supersonic wind tunnel. The flow in the water channel model of the wind tunnel is shown at the top of Figure 6.

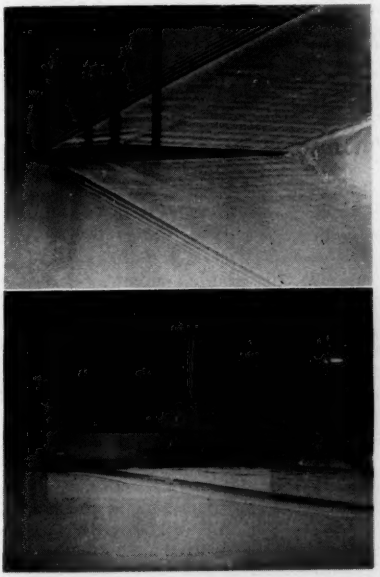

Figure 4. Overhead view (top picture) and side view (bottom picture) of the diamond airfoil (Figure 3) at $M = 2.47$.

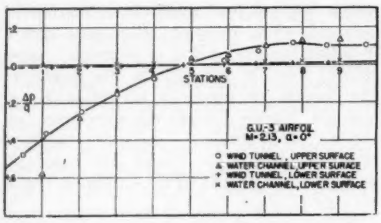

Figure 5. Comparison of water channel and wind tunnel pressure distributions.

This may be compared with the similar flow indicated in the Schlieren photograph of the wind tunnel, which appears at the bottom of Figure 6.

Naturally, use of the water channel and application of the hydraulic analogy have their limitations. Meniscus corrections need further study, and techniques for applying these corrections or a means of measuring the local water depth just outboard of the meniscus must be developed. A procedure for extrapolating two-dimensional data to represent three-dimensional flow conditions must also be developed.

It is believed, however, that so very much research remains to be performed in the field of supersonic aerodynamics that obtainment of two-dimensional data will prove to be well worthwhile even if the three-dimensional extrapolation is not ultimately accomplished. Current experiments give promise of eliminating the meniscus problem or at least of establishing the finite value of the required corrections. Either will make it possible to obtain good quantitative results from water channel experiments.

It is to be expected that after the program here has been fully evaluated, the true value of the use of the water channel will be obtained by employing it for tests on profiles that are not amenable to analytical methods and by subjecting such profiles to flow conditions such as accelerating or decelerating flow which cannot now be accomplished in a wind tunnel.

BIBLIOGRAPHY

1. Riabouchinsky, D., "Mecaniques des Fluides," *Comptes Rendu 22*, 998-99 (1932).
2. Binnie, A. M. and Hooker, S. G., "The Flow Under Gravity of an Incompressible and Inviscid Fluid Through a Constriction in a Horizontal Channel," *Proceedings of the Royal Society 159*, 592-608 (1937).
3. Preiswerk, Ernst, *Application of the Methods of Gas Dynamics to Water Flow with a Free Surface. Part I. Flow with Energy Dissipation*, U. S. National Advisory Committee for Aeronautics Technical Memorandum No. 934, Washington, 1940. 69 pages. *Part II. Flows with Momentum Discontinuities (Hydraulic Jumps)*, U. S. National Advisory Committee for Aeronautics Technical Memorandum No. 935, Washington, 1940. 56 pages.
4. Orlin, James, Linder, J., and Bitterley, Jack, *Application of the Analogy Between Water Flow with a Free Surface and Two-Dimensional Compressible Gas Flow*, U. S. National Advisory Committee for Aeronautics Technical Memorandum No. 1185, Washington, 1947. 20 pages.
5. Bruman, J. R., *Application of the Water Channel Compressible Gas Analogy*, North American Aviation Incorporated Engineering Report No. NA-47-87, Los Angeles, 1947. 60 pages.

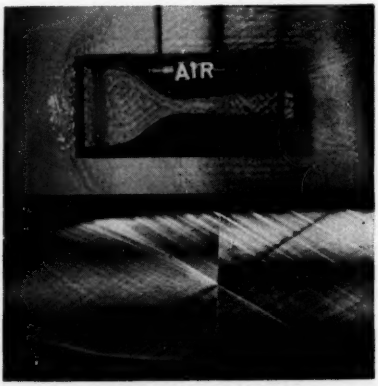

Figure 6. At top is the water channel model of a supersonic wind tunnel at M = 1.99. The bottom picture is a Schlieren photograph of this same supersonic wind tunnel, also at M =1.99.

RESEARCH BROCHURE

Georgia Tech's facilities for research and development are described in a new brochure which is available to those interested in the possibilities of the services afforded. This brochure describes how research is conducted here and depicts briefly the facilities available in each field of science and engineering.

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